OREGON WASHINGTON
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-311 January 1978

RATES OF SPREAD OF WILDFIRE IN ALASKAN FUELS

by

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ABSTRACT

Fire spread relationships are needed as a basis for categorizing and quantifying "real world" rates of fire spread in Alaska. The rate of fire spread predicted by the fuel models used to develop the National Fire-Danger Rating System were related to actual rates of spread observed on wildfires. General fuel models and local weather information provide a fairly accurate prediction of rate of spread. Data discussed can provide an interim guide for decisions on fire management and land management planning.

KEYWORDS: Fire behavior (forest), fire danger rating, fuel (forest fire), wildfire, tundra, Alaska, models.

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INTRODUCTION

There is a need for quantitative measures of rates of spread of wildfire for various Alaskan fuels. Information on fire spread in the interior of Alaska is almost nonexistent. The basic objective of this study is to provide field data from observations of fire in Alaskan fuels. There is a need for fire models for fire management and land management planning that can be used as a basis for comparison and further refinement of fuel models and fire behavior models.

Determination of rates of fire spread is very important in control operations, not only for long-range planning but for dispatching the initial attack. Fire spread rates are also important to the land management planner in assessing possible outcomes of alternate management strategies. A concerted effort has been made to develop rate-of-spread prediction models for fires (Rothermel 1972). As pointed out by Albini (1976b), fire behavior models have a wide array of potential uses, ranging from land use planning to prescribed fire design to decisionmaking. Today we use the inputs of fire behavior models in the National Fire-Danger Rating System (NFDRS) (USDA Forest Service 1964) and in fire control planning.

Actual rates of spread were obtained to help verify mathematical predictions. The rate-of-spread observations reported are an attempt to provide a reference for management applications and future research efforts. Results reported offer a basis for projecting rates of spread in Alaska and also a basis for selecting fuel models for use in several management operations.

METHODS

Forest Service field crews measured rates of spread of wildfires in various fuel types and under various weather conditions throughout interior Alaska during the fire seasons of 1969, 1970, and 1971.

The Alaskan Bureau of Land Management fire control organization is occasionally overloaded by large numbers of concurrent lightning fires, and control action is taken according to a priority plan. As a consequence we were able to use free-spreading (control action deferred) fires for making our observations. Many levels of fire intensities were encountered, including extreme conditions during difficult fires and fire seasons. Observations were made when opportunities arose. The number of observations reflect this and are concentrated in more severe weather and fuel conditions.

We used a hand-held wind meter and a sling psychrometer to record the weather. Wind was measured at midflame height where values might be expected to be somewhat lower than standard 20-foot, open anemometer heights.

Only the general overall advancement of the fire front was considered important, so rate of spread was observed as a wave front phenomenon. Microscale observations, such as ignition of individual fuel particles, were not made. Spot fires were watched and considered in the computation of rate-of-spread measurement only if they contributed to the general spread of fire. Fires were observed on the heading (burning forward or upslope), backing (burning into the wind), and flanking (burning to the side) sections. Rate-of-spread observations were made for a minimum of 10 minutes, or a minimum spread of 100 feet. Rate of spread was then reported as feet per minute averages.

Procedures were necessarily flexible to cope with the wide range of conditions and situations encountered in wildfires. Measurement of distance was more refined for slower spread conditions. A tape was used to either estimate paces or measure distances on slow-moving fires. A pacing check for each observer was made prior to determining high rates of spread where pacing was necessary. Equipment used included a stopwatch, flagging, belt weather kit, forms, and instructions.

Each observation was begun by hanging flagging ahead of the fire front and measuring the distance to another flag located along a line normal to the flame front. The progress of the fire between flags was timed with a stopwatch. Current weather was observed simultaneously at a short distance (50 feet) from the fire where the radiation and wind effect of the fire were judged to be negligible.

ANALYSIS

The data were stratified to provide meaningful input to fire models. The primary stratifications for our analysis were cover type (fuel) and direction of spread of fire (heading, backing, or flanking). Mature and young cover types were pooled, then analyzed. The broader cover types of conifer, hardwood, mixed conifer-hardwood, shrubs and brush, leaves, grass, and tundra were used.

Because of the relatively small amount of field collected data, considerable variation was encountered. Results of the analysis shown here are, however, an attempt to provide information on spread of fires in Alaskan fuel types. They also show the fit of the model data with observed field data.

Rate-of-spread averages for fuel types and direction of fire spread were developed. Data from all weather conditions were pooled for the various factors and then averaged (table 1). Maximum and minimum spread rates are also shown to indicate the ranges encountered.

To relate field observations of fire spread to existing fire spread models, we used the various fuel models available (Deeming and Brown 1975, Albini 1976a) to compare our data with predicted rates of spread. Ambient weather conditions for a majority of our data were within a temperature range of 50°F to 69°F and relative humidities of 35 to 44 percent. Such conditions would result in a 1-hour timelag fuel moisture of 6 percent and a 10-hour timelag fuel moisture of 8 percent (Deeming et al. 1974).[2/] Using some basic data from another research study,[3/] we estimated the 100-hour timelag fuel moisture to

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[2/] See Deeming et al. (1977) for definitions of timelag fuels and timelag fuel moisture.

[3/] Barney, Richard J. Fuel moisture relationships in four Alaskan cover types. Unpublished report, on file at Institute of Northern Forestry, Fairbanks, Alaska.

Table 1--*Maximum, minimum, and average rate-of-spread values by fuel type and direction of fire*

Fuel type	Spread direction	Number of observations (N)	Maximum rate of spread	Minimum rate of spread	Average rate of spread
			- - - Feet per minute[1] - - -		
Conifer	Heading	13	66.0	1.0	15.35
	Backing	30	2.1	.1	.98
	Flanking	21	9.0	.3	1.94
Hardwood	Backing	2	3.0	.5	1.75
Mixed hardwood and conifer	Heading	3	6.9	1.8	4.3
	Backing	8	8.9	.2	3.8
	Flanking	1	--	--	1.0
Shrubs and brush	Heading	9	4.1	.7	2.60
	Backing	22	2.7	.9	1.94
	Flanking	3	2.3	1.5	1.97
Tundra, weeds, and grass	Heading	1	--	--	1.1
	Backing	15	2.0	.1	.85
	Flanking	2	1.7	1.0	1.35

[1] To obtain chains per minute, multiply feet per minute by 0.0152; to obtain chains per hour, multiply feet per minute by 0.909.

be 25 percent and green fuel moisture to be 60 percent. These estimates were substituted for fuel moistures which could not be measured in the field.

Fuel models were selected to represent cover types where spread rates were observed. These fuel models were NFDRS models E, F, and H (Deeming and Brown 1975). In addition, Northern Forest Fire Laboratory (NFFL) modifications of these fuel models were used (Albini 1976a). General descriptions of NFDRS fuel models are shown in table 2.

We used computer programs (Albini 1976a) to calculate rates of fire spread for selected fuel types and plotted the resultant curves. Our rate-of-spread observations in the field were then plotted on these graphs by cover type. We selected models which appeared to best fit our data.

Table 2--*Brief descriptions of National Fire-Danger Rating fuel models*[1]

NFDR fuel model	Characteristics of fuels	Examples
E	The fuel is primarily made up of hardwood leaf litter. It is made up of only 1-hour and 10-hour timelag fuels that are not compacted.	Closed canopy stands consisting of long-needled pines or hardwood stands prior to litter compaction including all oak-hickory associations
F	A dense cover of young shrubs containing small amounts of dead material characterizes this fuel. This fuel has little grass or litter which will carry the fire, and the foliage will not burn well.	Shrub association such as laurel, alder, manzanita, mountain mahogany, and young chamise
H	Compact litter with branchwood of moderate loading is found in this type. Fuels of the 1-hour, 10-hour, and 100-hour timelag categories are present.	Northern hardwoods; hardwoods after leaf fall becomes compacted litter; and short-needled conifers

[1] Adapted from Deeming and Brown (1975). More complete descriptions and a key for field use are contained in Deeming et al. (1974).

We were unable to identify and stratify the spread rates by fuel loadings in a manner compatible with the Rothermel spread model. Fuel loading was a refinement brought about after the early examination of these data. Nevertheless, information obtained in this initial work can be useful to those in fire control and fire planning activities within interior Alaska, as well as to other interested scientists.

When these study data are reviewed and the information applied, the generally accepted fire rate of spread and windspeed relationships in fine fuels must be kept firmly in mind (fig. 1). Forward rate of

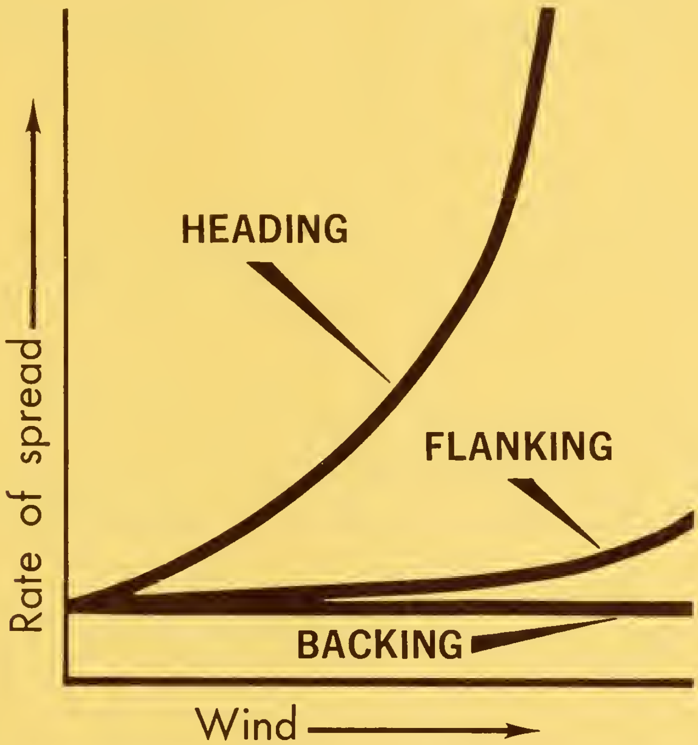

Figure 1.--Characteristic rate-of-spread curves of fires as wind increases.

spread is generally considered to increase as windspeed increases (Rothermel and Anderson 1966). The rate of spread of a backing fire is essentially constant throughout change of windspeed (Beaufait 1965). Flanking fires, however, generally increase their rate of spread with an increase in wind, but at a lower rate than a head fire.

Rates of Spread for Heading Fires

Rates of fire spread for the conifer fuel type were observed. Figure 2A shows these results. For the spread rates observed for heading fires in conifers there is a definite curvilinear relationship with windspeed. Although there is a considerable amount of scatter about the curve, the lower ranges of the data do show an expected pattern of increased spread rates with increasing windspeed. When

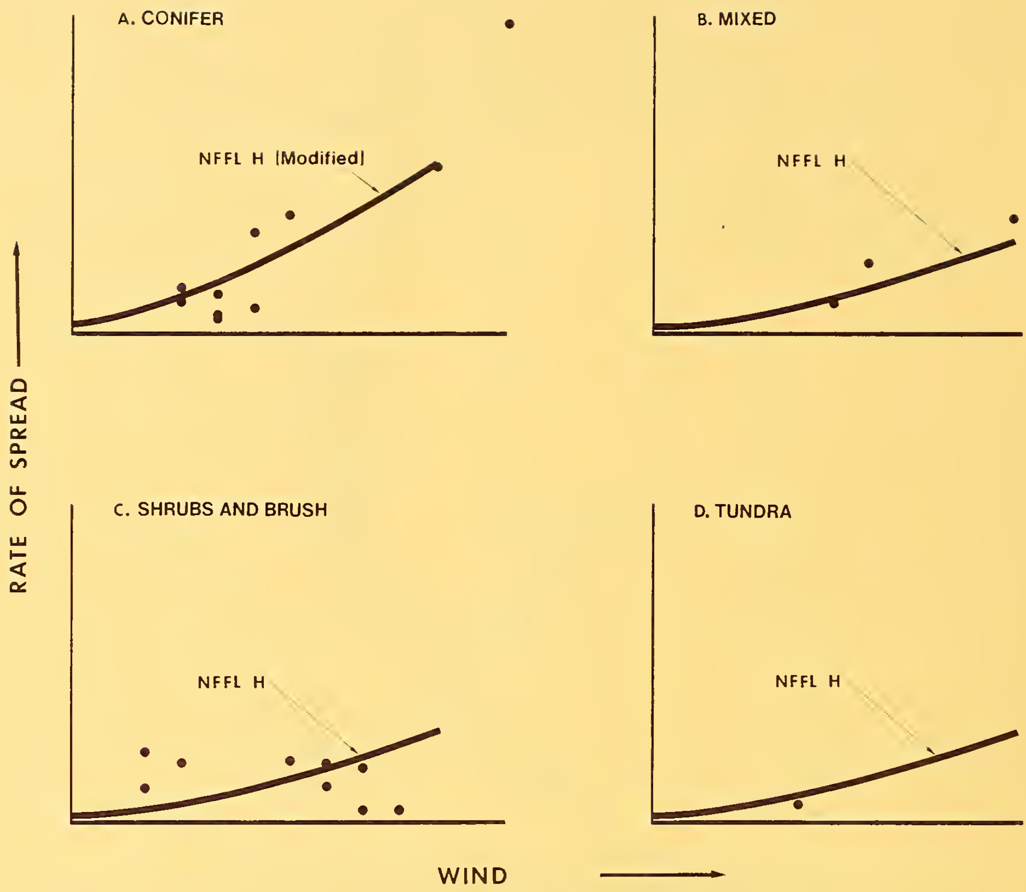

Figure 2.-- Rate-of-spread curves of heading fires in various fuels as wind increases.

figure 2A was plotted three data points were omitted; these points were fire spread observations with flame lengths of 80 feet. Fires of such magnitude are not adequately represented by the Rothermel spread model. The modified NFFL fuel model H seems to fit the rest of the observed data fairly well.

The mixed, shrubs and brush, and tundra data for heading fires are compared with data plotted by the NFFL H fuel model. Although the data for the mixed fuel (fig. 2B) are limited (three points), they do fit fairly well with the plotted curve. Data for shrubs and brush fit least well with the plotted curve. In some respects the data hint at an inverse relationship--that fire spread decreases slightly with an increase of wind (fig. 2C). The one point for a tundra fire fits fairly well with the NFFL model H curve (fig. 2D).

After the observed and the predicted spread data derived from the ambient conditions and fuel models were analyzed, the NFFL model H appeared to best fit our data. By slightly modifying the NFFL model H by increasing the depth of the fuel bed, we obtained an even better fit with the conifer data of the NFFL model H (modified). For each data plot displayed and discussed, we have plotted the predicted rate-of-spread curve for comparison. The specific fuel model inputs are shown in table 3; data presently incorporated in the NFDRS fuel model H are

Table 3--*Principal descriptors*[1/] *of fuel models*

Fuel model	Fuel loadings by classes				Surface-volume ratio by classes				Bed depth[2/]	Moisture extinction dead fuel
	W_1	W_{10}	W_{100}	W_{Live}	σ_1	σ_{10}	σ_{100}	σ_{Live}		
	- - - Tons per acre - -				- - - - - - $Feet^{-1}$ - - - - - -				Feet	Percent
National Fire Danger Rating System model H	1.0	1.0	1.0	--	2000	109	30	--	0.4	0.25
Northern Forest Fire Laboratory model H	1.5	1.0	2.5	--	2000	109	30	--	.2	.25
Northern Forest Fire Laboratory model H (modified)	1.5	1.0	2.5	--	2000	109	30	--	.3	.25

1/ Descriptor subscripts indicate 1-hour, 10-hour, and 100-hour timelags, and living woody fuel classes.
2/ Bed depth represents average depth of the fuel bed, all fuels touching the surface.

also shown. Basically, the NFFL H and NFFL H (modified) have a greater loading than the NFDRS model H in the 1-hour and 100-hour timelag fuels and also have a slightly deeper fuel bed. Rate-of-spread outputs for NFFL fuel models H and H (modified) are shown in table 4. Byram's (1959) fireline intensity is also shown.

One must keep in mind that the NFFL H and H (modified) curves were developed for selected weather and fuel moisture data. Our spread observations were not stratified by moisture in these plots, and different comparisons probably would have resulted had this been done. For so few points, however, stratification is not reasonable. Had more specific fuel loading and moisture content data been available for our field observations, we could have done more in the way of validating the spread model.

Rates of Spread of Backing Fires

For backing fires the spread rates for conifer fuel (fig. 3A), for weeds, grass, and tundra (fig. 3B), and for shrubs and brush (fig. 3C) are relatively constant as windspeed increases. In figure 3, A and B, rate of spread appears to increase as wind increases up to about 5 miles per hour. As the windspeed continues to increase, the rate of spread appears to drop off slightly. The data for backing fires follow the generalized spread relationships (fig. 1) of an essentially constant rate as wind increases.

Data plotted for the mixed (hardwood and conifer) type (fig. 3D) and the hardwood type (fig. 3E) illustrate more scatter. The rate of spread varies because of the heterogeneous nature of ground fuels in the mixed cover type, as well as the extreme variation in fuel moisture both vertically and horizontally (see footnote 2, p. 3). The limited

Table 4--*Rate-of-spread outputs for Northern Forest Fire Laboratory fuel models H and H (modified)*

Windspeed at midflame height		Rate of spread	Byram's intensity[1/]
Miles per hour	Feet per minute	Feet per minute	Btu per minute per fireline foot
		MODEL H	
0	0	0.25	44.2
1.0	88.00	.42	73.6
2.0	176.00	.72	126.5
3.0	264.00	1.11	194.5
4.0	352.00	1.57	274.6
5.0	440.00	2.08	365.1
6.0	528.00	2.65	464.9
7.0	616.00	3.27	573.0
8.0	704.00	3.93	689.0
9.0	792.00	4.63	812.2
10.0	880.00	5.38	942.2
		MODEL H (MODIFIED)	
0	0	0.41	113.4
1.0	88.00	.73	200.5
2.0	176.00	1.30	357.1
3.0	264.00	2.03	558.3
4.0	352.00	2.90	795.3
5.0	440.00	3.87	1,063.2
6.0	528.00	4.95	1,358.4
7.0	616.00	6.12	1,678.5
8.0	704.00	7.37	2,021.6
9.0	792.00	8.70	2,386.2
10.0	880.00	10.10	2,771.0

1/ Byram (1959).

data do not support the backing curve of figure 1; they appear to show an increase in spread of fire as wind increases, whereas the model indicates a steady rate or even a decreased rate of spread with an increase in windspeed. Stratification of data by moisture levels and fuel loadings might well change this situation, however.

Rates of Spread of Flanking Fires

Much of the data show similar rates of spread for flanking and backing fires (fig. 4). These rates of spread are slightly slower for higher windspeeds, however. The rate of fire spread in the conifer cover type varies considerably, probably because of the variation in the amount and moisture of the fuel.

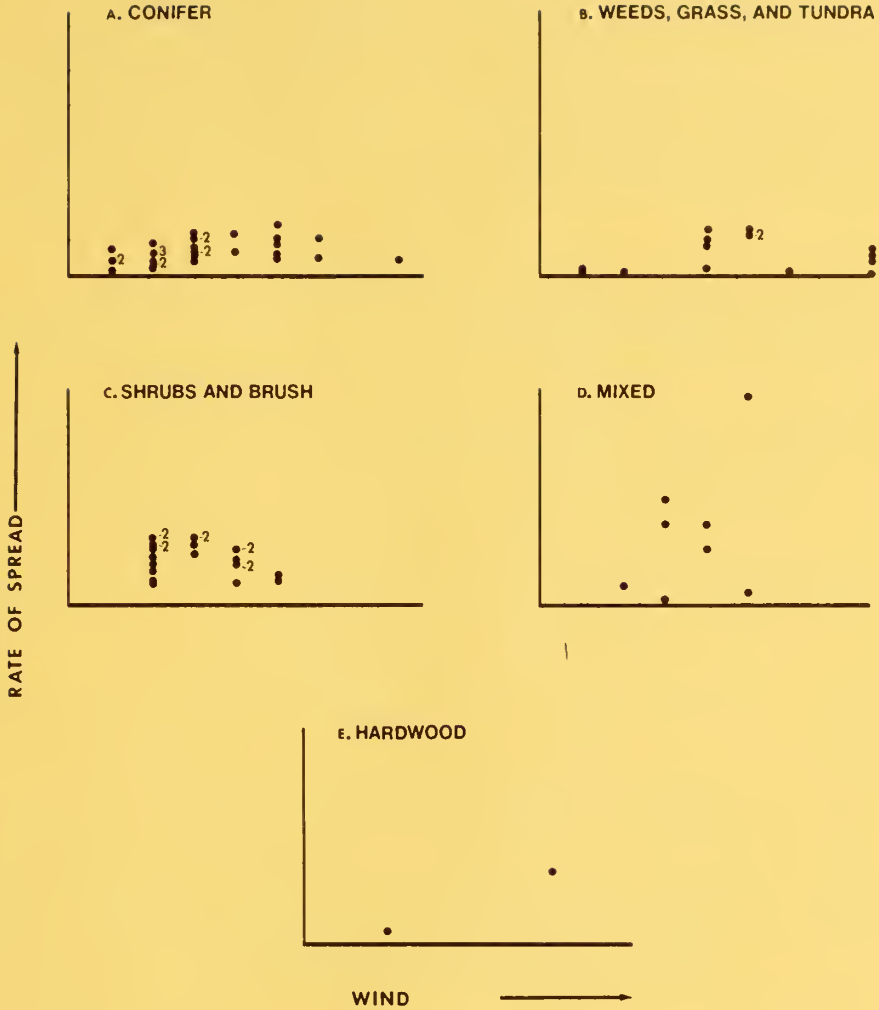

Figure 3.--Spread rates of backing fires in various fuels as wind increases.

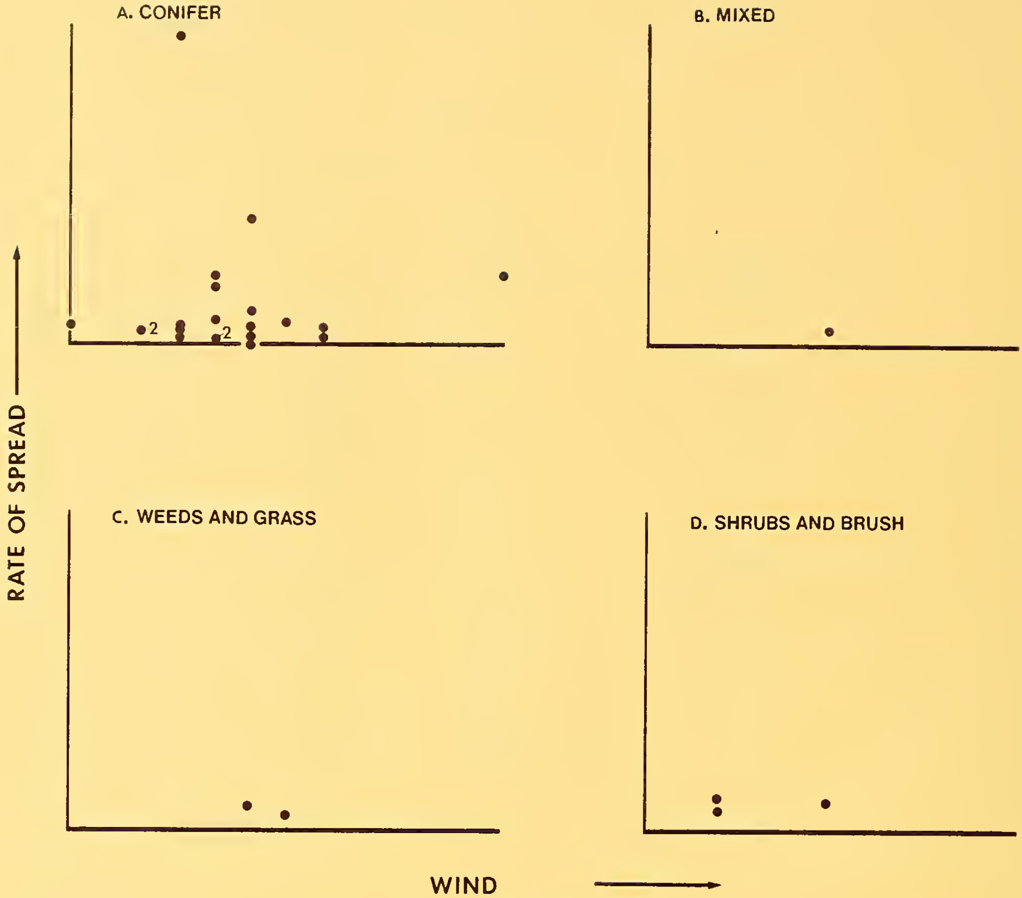

Figure 4.--Spread rates of flanking fires in various fuels as wind increases.

DISCUSSION AND CONCLUSIONS

Although the data vary considerably, they do provide some quantitative measures of fire spread for the various types of fuel in Alaska. The fuel models provide a basis for planning for both fire control and land management. We hope these data will help managers make a more accurate evaluation and projection of rates of spread than have been available for fuels in interior Alaska. The fuel models, along with local weather information, should give a fairly accurate prediction of rates of fire spread.

More data are needed, for both numbers of observations and types of data. More fuel moisture and fuel loading data along with fire spread rates would allow verification of spread and refinement of fire behavior models. Some relationships are weak, but they are a start at categorizing and quantifying "real world" rates of fire spread in Alaska. Continued work in describing the various fuels in Alaska, along with more sophisticated measurements of spread, will improve our understanding. These data can be used as an interim guide in making decisions on a quantitative basis, but the variations and limited amount of data must be kept in mind.

ACKNOWLEDGMENTS

The Office of Civil Defense provided partial funding for this study.

The U.S. Department of the Interior, Bureau of Land Management, Alaska Division of Fire Control, provided cooperation and logistical support.

CONVERSION FACTORS

If units are:	You can find:	If you multiply by:
feet	centimeters	30.48
miles	kilometers	1.61
degrees Fahrenheit	degrees Celsius	5/9 (after subtracting 32)

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GPO 985-118